Long title: Architectural correspondence, architectural misting and innovation: new perspectives

Short title: Architectural correspondence, architectural misting

Summary sentence: The relationship between innovation, product design, and industry co-evolution remains under-theorized. This paper discusses gaps in knowledge and introduces the contributing papers in this special issue.

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Introduction

The degree to which efficiency benefits are available to firms who choose correspond product and organization architectures has intrigued management scholars for around half-a-century. The idea that products design organizations, or organizations design products, latterly termed the mirroring hypothesis by Colfer (2007) and Colfer & Baldwin (2016) can be traced back through various literatures to the ideas of decomposable systems (Simon, 1962), information-hiding (Parnas, 1972), communication structures (Conway, 1968) and modularity theory (Sanchez & Mahoney, 1996; Schilling, 2000). Although Henderson and Clark (1990) and Sanchez and Mahoney (1996) never referred explicitly to a 'mirroring hypothesis', their seminal papers in Administrative Science Quarterly and Strategic Management Journal respectively were perhaps the first to lay claim to the idea that innovation / product design acts as a schematic for organization design. Henderson and Clark (1990), for example, recognized that mirroring can arise as "knowledge and information processing structure come to mirror the internal structure of the product they are designing" (p. 27). Sanchez and Mahoney (1996) noted that "…although organizations ostensibly design products, it can also be argued that products design organizations, because the coordination tasks implicit in specific product designs largely determine the feasible organization designs for developing and producing those products" (p.64). Following, scholarship on mirroring has grown substantially since Langlois and Robertson's (1992) study of the microcomputer and stereo systems industries, with a significant and growing number of studies published that examine the extent to which groups of modular (specialized) organizations produce modular products and vertically-integrated firms produce integrated products (eg. Burton & Galvin, 2018a; Colfer & Baldwin, 2016; Cabigiosu & Camuffo, 2012; Funk, 2008; Galvin & Morkel, 2001; Hoetker, 2006, MacCormack, Baldwin & Rusnak, 2012).

The mirroring hypothesis holds when the structure of an organization mirrors its technical product (eg. Colfer & Baldwin, 2016). Complementing this formal idea, recently scholars have suggested a 'reverse mirroring hypothesis' (Campagnolo & Camuffo, 2009; MacDuffie, 2013; Sanchez, Galvin & Bach, 2013) whereby 'organizations design products', an extension of Conway's (1968) Law, "organizations which design systems . . . are constrained to produce designs which are copies of [their] communication structures." (p. 31). The general idea of the mirroring hypothesis then is that a product system can be divided into various sub-systems, components, sub-components, and so on (Burton & Galvin, 2018b; Sorkun & Furlan, 2017). To the same extent, an organizational system can also be divided into strategic business units, programmes, projects and specialized teams, and an industry structure can disaggregate into a number of specialized firms along an industry value chain as a network of 'modular organizations' who coalesce around a particular product design (Sanchez & Mahoney, 2013; Schilling & Steensma, 2001).

The mirroring hypothesis seeks to examine the presence or absence of two bi-directional relationships. First, the correspondence between the product system (or 'architecture') and firm architecture – a 'within-firm mirroring', and, second, between these architectural choices and the prevailing industry architecture – an 'across-firm mirroring' (Burton & Galvin, 2018a; Colfer, 2007; Colfer & Baldwin, 2016). Scholars in the modularity tradition have argued that an across-firm mirroring hypothesis holds when either a vertically integrated firm develops integrated products or a group of specialized organizations along an industry value chain develop modular products. Langlois and Robertson (1992) implicitly recognised this potential correspondence between modular product designs and industry structure by observing that "by allowing specialist producers…to concentrate…on particular components, a modular system thus enlists the division of labour in the service of innovation" (p.302).

For strategizing managers, the design challenge is to create a technical product architecture and corresponding organization architecture that is capable of carrying out product development tasks efficiently and effectively, but as the number of empirical studies has increased, a considerable number have revealed contradictory findings leading to a growing literature on architectural 'misting' or 'breaking the mirror'. Sorkun and Furlan (2017) noted that different research settings do not explain the contradictory findings and that the presence of architectural mirroring or misting relates to various contingent factors, often related to technological considerations. For example, Colfer and Baldwin (2016) noted while mirroring may confer some efficiency benefits to firms, "…a strictly mirrored system may preclude firms from anticipating or pursuing architectural innovations. In other cases, it may be prohibitively costly or logistically infeasible. Thus, architects and managers may trade-off the economy of strict mirroring in favor of other benefits or in response to organizational limitations and constraints. They may consciously seek to create partially mirrored systems or even unmirrored systems" (p.716). This begs the question under what conditions is it beneficial for firms to mirror or mist product and organization architecture?

Bach and Galvin note in this special issue that the benefits of mirroring architectural pairs arise from efficiency and strategic flexibility associated with creating and capturing value from both gains from trade and gains from specialization (see also Burton & Galvin 2018a+b; Jacobides, 2005; Sanchez, Galvin & Bach, 2013). Scholarship has also noted other benefits that may accrue to mirrored organizations such as more efficient communication and control (Querbes & Frenken, 2018), simultaneous and in-parallel product development (Gomes & Joglekar, 2008: Sanchez, 2013), conservation of scarce resources (Colfer & Baldwin, 2016; Sorkun & Furlan, 2017) and reduced sourcing costs (Hoetker, Swainathan & Mitchell, 2007). Given these

potential benefits, why then do the majority of across-firm studies show that mirroring is either difficult to sustain or is even undesirable?

Much of the work on misting has explored architectural non-correspondence between the boundary of the technical product architecture and firm boundaries. According to Colfer and Baldwin (2016), the mirror is misted or broken when either a co-located (or 'integrated') product development team within a single firm designs a modular architecture – a closed and modular product architecture – or where an integrated product architecture is designed via buyer-supplier relationships – an open and integrated product architecture[1]. In the case of closed and modular exceptions, a modular product is designed within a single firm boundary. For example, Hoetker's (2006) noted this type of misting in the computer notebook industry, Black and Decker created an internal range of power tools with standardized components (Lehnerd, 1987), Sony designed the Walkman in the same way (Sanderson & Uzumeri, 1995), and Langlois (2002) recounts the example of IBMs computer systems in the 1970s as a form of internal modularity, whereby IBM sought to keep its modular interfaces proprietary and to prevent external firms from supplying modular product components. In contrast, Argyres (1999) examined the development of the B2 stealth bomber and found that the integrated technical requirements of 'stealth' had the effect that no-one single firm held all the capabilities and knowledge to develop the product independently, and hence development proceeded with input from multiple firms by establishing a set of standardised rules, procedures and systems. Colfer & Baldwin (2016) also noted numerous examples of misting in open innovation projects.

[1] For work on product architecture typologies, see Burton and Galvin (2018a+b; Sanchez, 2008)

Colfer (2007) identified that a correspondence between knowledge boundaries and firm boundaries may act as a strategic opportunity for mirroring. Sanchez and Mahoney (1996) noted that firms can achieve competitive advantage through decomposing the knowledge about its product design into bundles of architectural and component knowledge. The focal or 'lead' firm then focuses on architectural knowledge, enabling it to outsource component level tasks and its related knowledge across firm boundaries. Once architectural and component level knowledge is decomposed, the division of labour can then mirror the division of knowledge either within or across firm boundaries (Burton & Galvin, 2018a). Despite these potential benefits, the decomposition of knowledge boundaries into architectural knowledge and component knowledge (see also, Sanchez, 2003) has been challenged, and a number of architectural misting studies have noted a non-correspondence between knowledge boundaries and firm boundaries. For example, Galvin and Rice (2008) noted that product design and development requires both component and architectural knowledge integrated into an 'information structure' that acts as the relevant unit of analysis to determine decisions around the division of labour. Brusoni, Prencipe and Pavitt (2001) noted that it can be difficult for a group of firms to develop a modular product without a 'systems integrator' who orchestrates the activities of others, recomposes the modules, and who must "…know more than they do" (Brusoni & Prencipe, 2001, p202). Since complex products are composed of different components with different technologies, a systems integrator may undermine its future performance if it does not retain knowledge of outsourced components.

Despite prior studies that have explored misting relationships, Burton and Galvin (2018a) noted that scholarship on the mirroring hypothesis has only recently turned to focus upon the contingent conditions under which it may hold rather than whether or not it holds (ie, Furlan, et al., 2014; Sorkun & Furlan, 2017). In their recent literature review, Sorkun and Furlan (2017)

noted six contingent factors in the extant literature: component technological change and diversity; innovativeness of product architecture; complexity of the product architecture; capability dispersion along the supply network; rivalry among leading firms and among suppliers; and, logistics costs. Much of the work on 'contingencies' has explored the product architecture level (eg. Complexity) and the product component level (eg. Rate of technological change). The complexity of the product architecture (eg. MacDuffie, 2013; Sosa, Eppinger & Rowles, 2004; Zirpoli & Camuffo, 2009) has been associated with a need for increased coordination and control between firms along an industry value chain. For example, Sosa, et al., 2004 show the extent to which product complexity causes organizations to understand and resolve component interdependencies causing richer coordination and control mechanisms. Zirpoli and Camoffo (2009) noted that product complexity causes a misting of knowledge and task boundaries, and argued that organizational factors such as its strategy and its prior knowledge and capabilities determined task boundaries more so than the product architecture. However, even when the product architecture is characterised as 'simple', modularity may also be difficult to sustain in dynamic contexts (Furlan, et al., 2014; Langlois, 2002). Furlan, et al., (2014) examined the air-conditioning industry and noted that non-correspondence can occur in the presence of component level technological change. The authors suggest that product component change increases information asymmetry and asset specificity and this leads to more frequent communication and collaboration between buyers and suppliers, regardless of the degree of component level modularity. In addition, firms retained access to component knowledge in order to keep up with technological change. Sorkun and Furlan (2017) also noted that the diversity of component technologies in a product architecture is another reason that leads to the richer buyer-supplier relationships.

Given that the mirroring hypothesis examines the link between product and organization architecture, when product technologies change – as a result of innovative activity, for example - so too does a firm's task structure and firm boundary - and vice versa (Burton & Galvin, 2018b) - and this presents a strategic opportunity (Colfer & Baldwin, 2016). Burton and Galvin (2018a+b) have recently begun to examine the temporal characteristics of mirrored and misted architectural relationships, and highlight that phases of mirroring and misting that follow architectural and/or modular innovation were common the in UK financial services industry between the mid-1980s and 2014. In their study, the primary drivers of such architectural changes were technological innovations and regulatory change. Wolter and Veloso (2008) also explored the effects of architectural and modular innovation on firm boundaries. They noted that modular innovation increases the degree of outsourcing due to reduced transaction costs and co-ordination needs, whereas architectural innovations increase the level of vertical integration owing to the reintroduction of transaction costs and coordination needs. Similarly, McDermott, et al., (2013) argue that modular innovation is not without risks in dynamic product market environments and under high rates of technological change (Zirpoli & Becker, 2011). To cope with fast innovation environments, maintaining access to a broader knowledge boundary than task boundary – and thus forego strict architectural correspondence - may help firms overcome disruptive innovation (Brusoni & Prencipe, 2001).

Sorkun and Furlan's (2017) recent and extensive literature review of the 'product designs organizations' stream of the mirroring literature provided inspiration for this special issue. Sorkun and Furlan (2017) noted that neither differences in institutional context, nor differences in research methodologies or methods, explain the variance in whether architectural mirroring or misting is present or absent in different contexts. This led us to consider new directions for the literature. First, we noted that the reverse mirroring hypothesis – 'organizations design products' - had received much less attention in the literature and this is unfortunate and

pressing. Explorations of the reverse mirroring hypothesis is, we believe, ripe for further scholarship given that, to use the terminology of Puranam, et al., (2012), the reverse mirroring hypothesis may shed more light on the 'epistemic interdependencies' that exist among organizational actors even where the components are modular. We were also intrigued by the fact that the mirroring hypothesis literature has rarely moved beyond manufacturing or production-based industries such as automotive, aircraft, and IT hardware, and we were open to scholarship from the service and/or knowledge-based economies in order to complement existing studies and advance theory. We were also open to fresh ideas that took mirroring ideas in new directions. For example, the extent to which architectural mirroring or misting might facilitate or hinder international business expansion and the emergence of globalized value chains. Given that modular products offers scope for mirroring task, knowledge, firm boundaries and national/international boundaries, we were especially interested in the extent to which the mirroring hypothesis is present or absent across international boundaries. Finally, given that innovation is central product design and the location of task, knowledge and firm boundaries, we were especially interested in exploring the extent to which innovation is associated with product and organization design and/or firm performance outcomes. Thus, we welcome a number of papers that explore innovation modes and its implications for firm performance outcomes.

Contributions to this special issue

In the first four papers, the contributions focus on extensions to the extant reverse mirroring hypothesis literature. The first three papers by Mafimisebi, Obembde and Aluko, Bach and Galvin, and Mendy examine the reverse mirroring hypothesis from the perspective of organization design and the individual characteristics of CEOs and those involved in implementing new products and services. The fourth paper by Burton, Nyuur and Amankwah-

Amoah is located within the ‘products design organizations’ stream of the literature, and the authors consider the extent to which the modular characteristics of a product can act as a substitute for formal managerial ownership and control and may provide an efficient system design for easier product localization in international product markets.

The first paper in the special issue by Mafimisebi, Obembde and Aluko examines the role of product innovation and dynamic capabilities in determining which architectural pairings of product and organization design emerge and sustain within a particular institutional context. Unlike authors who examine correspondence as running from product design to organization design, the authors examine the reverse mirroring hypothesis that runs from organization design to product design. The paper incorporates a dynamic capabilities perspective to argue that the breadth and scope of a firm’s ‘product innovation capabilities’ (PICs) determines organization design and ultimately its type of innovation and design of its product artefact. The scope of a firm’s product innovation capabilities, thus, substantially shapes – and determine the success of - the architectural design options available to strategizing managers.

The second paper in this issue continues the theme of ‘organizations design products’. Bach and Galvin argue that the correspondence between architectural pairs of organization and product design are not purely driven by external forces – the ‘iron cage’ of mirroring – but rather managerial discretion plays an important role in determining architectural choices. Given that the extant literature has shown substantial contributions from scholars who identify a ‘CEO effect’ on firm performance, the authors draw upon Upper Echelons theory to illuminate how individual CEO characteristics – such as age, tenure, education, experience, and personality - may also impact choices of organization and product design – and the degree to which those architectural choices mirror or mist. Given the well-established misting contingencies of the product-level characteristic of complexity, and the component-level characteristic of the rate of technological change, Bach and Galvin contribute to the growing literature on reverse

architectural misting by highlighting how individual CEO characteristics relate to product complexity and component level change and thus to architectural mirroring or misting.

The third paper by Mendy continues to extend the literature through an exploration of the extent to which factors at the both the organization level and at the level of individuals involved in innovation and product design may lead to a misting between actual and desired mirroring. Mendy locates his study within the context of SMEs – an underexplored phenomenon in the mirroring literature. Mendy conducted eight-five interviews in four internationally-connected SMEs and argues that while mirroring may be possible between organization and product design, misting often occurs during the implementation stage of new products and/or services. Product and/or service redesign are invariably related to a firm's culture, values and the personal objectives of those involved in the implementation process, and these organizational factors may lead to an obscurification of the intended strategy, especially in SMEs where the decomposition of tasks and activities may be more difficult to achieve. Thus, in SMEs the individual preferences of managers and designers may act as a schematic for organization design more so than the product / service architecture.

The fourth paper by Burton, Nyuur and Amankwah-Amoah utilizes modularity theory and the 'product design organizations' perspective to illuminate the extent to which integrated or modular product architectures facilitate or hinder international product market expansion. By synthesising modularity theory with the international business literature, the authors argue that the interface standards characteristic of modular products provide a form of embedded coordination and control that substitutes for the ownership and control benefits often assumed in foreign direct investment and other equity-based ownership structures. The authors contend that the strategic flexibility and opportunity for significant levels of component variety in modular products – through easier and faster component level innovation – enables firms to more easily 'localize' the product design and/or comply with numerous and varied 'national

standards' regimes in multiple different countries simultaneously, and thus modular products may confer the potential for an international competitive advantage (eg, through exporting). Moreover, the authors highlight that the embedded coordination within the design of modular products offers the opportunity to, but not a necessity to, transfer design and production to international value chain partners and potentially benefit from lower costs or other performance benefits. In contrast, integrated product architectures are often extremely difficult to reengineer to new uses or product markets without significant architectural innovation and thus these kinds of products are often more dominant in home market contexts and are less well-equipped to form part of a broad internationalization strategy.

The fifth paper by Liedong, Peprah and Eyong provides another important extension to the literature on product architecture types in international product markets (eg. Emerging markets). Drawing upon institutional voids theory, the authors argue that the presence or absence of institutional voids in emerging markets variously affects the decision whether to adopt a closed or open product architecture as the bases of product market competition. Closed product architectures achieve advantage through means such as ownership and protection, and open product architectures rely upon extensive collaboration and the sharing of standards along an industry value chain. Unlike the hypothesis argued by Burton, Nyuur, and Amankwah-Amoah, in the context of emerging markets, the authors find that open product architectures are often more difficult to internationalize than closed product architectures owing to the absence of an institutional framework (eg. Standards, availability of partner firms, etc). However, this generalized observation is moderated by two important caveats. First, where a foreign firm and emerging market partner collaborate in product design along an industry value chain, emerging market partners may be 'imprinted' by best practice that leads to the emergence of standards-based innovation governance modes. Furthermore, emerging market partner organizations may be 'politically-connected' and such connections -

eg. Government resources and support - confer benefits to both the emerging market partner firm and the foreign firm and thus promotes more extensive collaboration.

The following five papers each examine the role of innovation and its relationship with, in various ways, to product and/or organization design and outcomes. The sixth contribution by Galvin, Burton and Bach is firmly located within the modularity tradition and explores the extent to which firm-level outcomes are influenced by the ownership and control dimensions of a modular product architecture. The authors also contend that modular innovation brings to the fore vital strategic issues for managers to do with the types of innovation that are feasible – issues that have been shown in various literatures to be critical for value creation and capture. The paper characterizes modularity – and the mirroring of product and organization architectures - as a series of trade-offs that managers need to navigate. In the case of ownership and control, modular product architectures can be owned and protected by a single firm, but this is then a decision to forego the innovative potential of external specialized firms along an industry value chain, and potentially also forego network externalities and option value. In contrast, 'closed' modular products may confer ownership advantages and mitigate risks of commoditization and imitation. In a similar way, modular products may confer innovation advantages to firms by being able to create multiple versions of a product quickly and easily for heterogeneous product markets, but they are also at significant risk from radical and architectural or 'game-changing' innovations that make it almost impossible for sponsors of modular products to react to.

The seventh paper addresses innovation from an architectural perspective and its relationship to knowledge creation. Azzam, He and Sarpong sample one-hundred and ninety-six UK manufacturing companies and stress the potential for value creation and capture from architectural and 'game-changing' innovation. They argue that superior knowledge nodes related to socialization, internalization, and externalization drive the capacity for architectural

innovation. The paper confirms prior research in the modularity tradition that decomposing and outsourcing knowledge modules runs the risk that the knowledge required to pursue architectural innovation is subject to decay and loss. Retaining both architectural and component knowledge, the authors argue, is essential for identifying and designing architectural innovations in new product development.

The eighth contribution by Atiase and Dzanski examines the Global Entrepreneurship Index for thirty-five African countries to uncover the antecedents of successful product innovation in emerging markets. The authors draw upon creativity theory to find that the constructs of human capital and competitiveness are the main drivers to successful product innovation among firms in Africa. Networking also provides some benefits but less than the extant literature suggests. The paper argues that collaboration and networking along industry value chains in Africa are institutionally- and culturally-determined; while networking and co-creation could reduce costs, improve innovative and technical activity, and disperse knowledge and capabilities, African firms are found to be less willing to share proprietary knowledge and collaborate with potential partners, preferring to create and capture value from internalization.

The ninth contribution investigates innovative capability and its relationship to organizational performance in the Jordanian baking sector. From the literature, Al-Kalouti et al., identify four constructs of innovative capability – organizational culture, knowledge-sharing, resource management, and effective customer engagement – and show how each construct is correlated to both financial and non-financial success indicators.

The tenth – and final – contribution from Sammour, et al., examine the innovation S-curve theory in relation to the John Lewis Partnership – an example of a ‘corporate heritage brand’. Through historical case analysis, the authors find that John Lewis Partnership underwent several innovative episodes at the organizational level which they classify as periods of

invention, sustainability, expansion, and extension. The longevity of the success of corporate heritage brands, such as John Lewis Partnership, they attribute to its ability to continually innovate and reinvent. The contribution lies in how the authors illuminate how S-curve innovation theory can be utilized to analyse organizational-level innovations, in addition to product and process level innovation.

Conclusion and future research

The collection of papers in this special issue offer multiple new perspectives on architectural mirroring and misting and the role of innovation in new product development and organization design / outcomes. Further opportunities for exploration in this terrain present themselves. First, there is a continued need for further empirical research on the contingent factors that may obscure the mirroring hypothesis / reverse mirroring hypothesis. Sorkun and Furlan (2017) noted in their literature review that future scholarship might specifically address the moderating effect of the identified contingency factors on the product and organization relationship. In this special issue, we have taken steps in this direction and contributions by Mafimisebi, Obembde and Aluko, Bach and Galvin, and Mendy have shown how the individual CEO or group/team characteristics within organizations may present further insights. This perspective could be enhanced further, for example, through exploring how the different 'visions' held by different stakeholders might influence innovation, product and organization design choices (see for example, Adegbile & Sarpong (2018).

Burton and Galvin (2018a) noted also that scholarship should move away from cross-sectional analysis to consider the temporal dimensions of architectural mirroring or misting. We urgently need detailed and careful retrospective or longitudinal studies that collect product data at the component, sub-system and architecture levels, organizational data at the team, department, project, and SBU level, and industry level data that identifies firms along an industry value

chain. This kind of data will necessarily require extensive mixed method studies within- or across industries. A temporal analysis of architectural mirroring or misting also raises important strategic questions regarding the extent to which product designers or organization architects who have selected a particular architectural configuration then have the strategic foresight or flexibility to respond to or initiate architectural and disruptive innovation (eg. Adegbile & Sarpong, 2018; Sarpong & Maclean, 2014).

We also urge scholars to extend analysis of architectural mirroring or misting into cross-border product markets and contexts. Elia, et al., (2017) and Burton, et al., in this special issue have opened up this line of enquiry, and scholars will need to carefully distinguish between the mirroring or misting of design tasks, production tasks, and distribution tasks in order to identify the extent to which different tasks are governed across national boundaries. Given that modular product architectures are often described as containing embedded coordination mechanisms, whether these mechanisms hold in different cultures and countries is ripe for further exploration. Like a number of scholars (eg. Affuah, 2001; Campagnolo & Camuffo, 2010; Sorkun & Furlan, 2017), a fundamental question concerns the performance implications of the mirroring hypothesis. Despite the prevalence of ideas that mirroring provides efficiency and flexibility benefits, the implication of a contingent view of architectural mirroring is that superior performance is achieved only in the absence of strict mirroring (eg. Pil & Cohen, 2006).

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